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CONTENTS

Page

Lighting in Coal Mines, by J. Ivon Graham, M.A., M.Sc., M.I.Min.E. - 123

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Lighting in Coal Mines*

By J. IVON GRAHAM, M.A., M.Sc., M.I.Min.E.†

Synopsis

The paper opens with a general review of the problems involved in mine lighting and steps which have been taken to improve conditions in the mines by providing better lighting. Attempts to improve illumination at the coal face over that possible by portable lamps have so far not shown any benefit in increased output but there appears to be evidence of a reduction in accidents.

The merits of electric hand lamps and cap lamps are discussed, and suggestions for possible future improvements are made. Alternative methods of providing adequate illumination at the coal face by means of transportable self-contained battery lamps and by mains lighting are discussed at some length and mention is made of the application of mains lighting to mines in other countries. A description is given of the pneumatic-electric lamp which provides a means of greatly increasing the illumination at the coal face in those pits where, for various reasons, mains lighting cannot be used.

The paper deals with the subject of glare and discusses methods for ensuring the maximum reflectivity at the working face.

Introduction

In their report issued in 1944(1), the Technical Advisory Committee appointed by the Minister of Fuel and Power under the chairmanship of Mr. (now Sir) Charles Reid, stated that "no man can work properly without good light, and this especially so when conditions are difficult.

"It is not easy to provide safe and satisfactory artificial lighting underground, and while recently the standard of illumination has considerably improved, more particularly following upon the lighting regulations of 1934, there is still room for improvement."

The coal miner of one hundred years ago probably enjoyed better illumination in his work than did the average miner fifty years later. With the realisation of the danger of firedamp, attempts were made to evolve a source of illumination which would not ignite inflammable gas, and although the Davy Lamp was successful in this respect, the amount of light given by the early forms of safety lamp was very low indeed. This will be appreciated from an examination of some of these early forms, which it is possible to exhibit to-day thanks to the kind help of Prof. J. A. S. Ritson. One wonders how the miner was able with such lamps to do any appreciable work. The answer lies in the wonderful capacity of the human eye to adapt itself to low illuminations. This faculty of acclimatization to low illuminations, possessed in varying degree by different individuals, is now well realised partly as a result of the extensive investigations made for the R.A.F. on darkness adaptation in connection with night flying. It is probable that in past years many miners had less than 0.05 foot-candle on their work for the greater part of the working shift, and at the end of the shift the illumination was probably in the neighbourhood of 0.01 foot-candle. Although the light given by the miner's safety lamp was improved both by better combustion of the liquid fuel and by the use of better quality oil, nevertheless even as recently as 1930, it was found from information obtained on behalf of the British Colliery Owners' Research Association, at

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† Scientific Dept., National Coal Board.

the request of the late Dr. J. S. Haldane, that the average candle power given by an oil lamp at the end of a shift, was less than 0.5. Assuming the lamp to be at an average distance of 3 ft. from the work, the illumination on it cannot have been more than 0.05 ft.-candles.

Clearly illumination of this order, which is less than one-hundredth of that recognised by the Factory Department of the Ministry of Labour as being requisite for satisfactory illumination of work in factories, is, in spite of the adaptability of the human eye, very much too low. The miner's occupation is hazardous, and increased illumination should help to lessen the risk from accident and particularly accidents such as hands trapped in machinery. Attempts made in this country to make a distinct improvement in the illumination on the coal face, for example, by installation of mains electric lighting or by means of pneumatic electric lamps, have in fact shown a reduction in accidents, although nothing definite in the way of increased output has been proved. Again, the disease miner's nystagmus, which at present costs the industry over half a million pounds per annum in compensation, seems to be closely connected with deficiency in illumination. In addition to the financial loss due to compensation, there is the more important loss of valuable trained personnel which at the present time is difficult to replace, and further the reduced efficiency of those who suffer from the disease but who have not yet applied for compensation. Moreover, if improved illumination can be brought about without giving rise to glare, an increase in working efficiency at the coal face should follow. In view of the advances in mechanisation which have taken place in recent years and are likely to increase further, considerable improvement in illumination underground on haulage roads as well as on the coal face is necessary to ensure greater output, greater safety and cleaner coal. Furthermore, there is the beneficial psychological effect upon those engaged in the industry, which should be produced by a much improved standard of lighting generally underground, an improvement which should enable the miner, starting at the pit top in a well-lit, whitewashed or painted cage, to travel thence along well-lit underground roadways to an efficiently illuminated coalface. The effect of such conditions upon new entrants into the coal mining industry would, it is believed, be very marked indeed.

During the past half century many attempts have been made by individuals, committees, technical institutes and the Government, to improve the standard of mine lighting. These attempts are illustrated by the many papers on the subject which have appeared in the mining technical press, and indicate the efforts of mining engineers and others to improve conditions. The first report of the Nystagmus Committee in 1923 drew attention to the effect of poor illumination, and the work of the Joint Committee of the Institute of Mining Engineers, the Mining Association, the National Association of Colliery Managers, and the South Wales Institute of Engineers helped, without doubt, to stimulate the manufacturers of miners' lamps, both electric and flame types, to produce equipment which was capable of meeting the requirements of the mine lighting regulations which came into effect at the beginning of 1934. The improved types of lamps, both hand and cap, increased the illumination on the miner's work at least fourfold.

In this paper the present position in regard to portable lamps will be briefly outlined, and, in doing so, the author would like to express his indebtedness to members of the various panels of the sub-committee on Mine Lighting* (of which sub-committee he has the honour to be chairman), and on whose report (2) he has drawn.

* National Illumination Committee.

Portable Lamps

Until the end of the nineteenth century flame lamps were in almost universal use. Only a few electric hand lamps were employed, and these were very inefficient. The offer, in 1912, by the Mining Association of a prize for the best design of an electric hand lamp helped the production of a practical lamp, but nothing of outstanding value came into general use until the introduction of legislation in 1913. Thereafter little improvement in the illumination given by hand lamps took place until 1934.

In the case of the hand lamp the improved illumination was in the main brought about by increasing the wattage of the bulb, rendering a larger battery necessary. The alkaline cell giving 2.6v. had an advantage in weight, but a greater voltage drop with time than the acid cell. The 4v. lamp with acid battery was actually lighter in weight, but even so, the weight of the latest type of hand lamp (11 lb.) is as much as the miner can be expected to carry. (Some of the latest types of hand lamps were shown and made interesting comparisons with the lamps in use twenty-five years ago.)

Attempts to increase the illumination of the flame lamp were not unsuccessful, and high candle-power flame lamps giving 4 candle-power were evolved. These, however, suffered from the drawback of excessive heat and also in being rather too easily extinguished. On the other hand, the soft yellow light and greatly reduced glare made this lamp appreciated by many.

Attempts to reduce glare by the introduction of coloured lamp glasses at first met with approval, but later it was realised that much of the light was

TABLE I

Lamp performance

Type of Lamp	Candle-power before shift	Candle-power after shift
Oil-lamps	0.7	0.4
Ordinary electric hand-lamp (2 volt.) (Acid and Alkaline)...	1.2	0.7
Ordinary electric (Acid)...	1.25	0.75
„ „ (Alkaline)	1.1	0.6
Cap-lamps :		
(*a*) Old reflector	3.7	1.7
(*b*) New reflector	6.4	2.6
Large or high candle-power lamps, Alkaline 2.6 volts	3.7	1.8

lost by absorption by the coloured well-glass. Other efforts to reduce glare have been confined to the design of prismatic well-glasses.

The low illumination produced by both electric and oil lamps was not sufficiently realised until, in 1929-30, at the suggestion of the late Dr. J. S. Haldane, some 16,000 lamps were tested before and at the end of the working shift by Dr. T. David Jones and others (3) with the Haldane lamp-room photometer The results for average candle-power are given in Table 1 (taken from the report of the Mines Lighting sub-committee)(2).

The highest average for a colliery for oil lamps was 0.9 c.p. before and

0.6 c.p. after the shift, while the minimum average for a colliery was 0.5 c.p. before and 0.3 c.p. after the shift.

The markedly higher illumination given by the alkaline 2.6v. lamp just introduced about the time of the tests is illustrated in Table II, but it will be seen that the drop in candle-power at the end of the shift was considerable.

A recent publication of the Ministry of Fuel and Power, entitled "Report upon the Lighting Performance of Safety Lamps in Coal Mines in Lancashire and North Wales" (Stationery Office, 1946), emphasises that poor lighting has frequently prevented men from avoiding accidents. Defects in the roof may not be discovered owing to poor lighting until too late for steps to be taken to

TABLE II

Lamp performance with alkaline accumulators

Type of Lamp	Candle-power before shift	Candle-power after shift
A	4.0	1.6
B	3.6	1.9
C	4.8	2.7

secure safety. Examination of the top of high rippings proves difficult and this lack of information adds to the danger of men who have to pass underneath.

The report showed that 29 per cent. of the flame lamps and 36 per cent. of electric lamps failed to reach 50 per cent. of the lighting value of the lamps when new, and pointed out that this was mainly due to unsatisfactory lamp-room maintenance. Improvement could be effected by attention to detail and cleanliness in lamp rooms, combined with training and education of the staff. It should be pointed out that general regulation 3 of the Coal Mines General Regulations (Lighting), 1934, simply specifies that safety lamps to which these regulations apply shall be manufactured and used in such a manner as to secure their lighting performance in service against an unreasonable rate or extent of deterioration. In an appendix to the report, Major C. B. Platt, H.M. Testing Officer, and Mr. Frazer, H.M. Divisional Inspector of Mines, consider that Schedule A miners' lamps should be required by legislation to be maintained so as to give an illumination at an average level of 75 per cent., and that individual lamps should not fall below 60 per cent. of the original performance of the type of lamp comprising the installation.

Although there is a great need for improvement in the standard of underground illumination which cannot possibly be supplied by the present type of portable hand lamps, nevertheless it is desirable to encourage attempts to obtain the best possible utilisation of the energy of the battery. This can be done by (1) increasing the candle-power per watt by a reduction in the life of the filament from 600 to 300 hours; in others words, by running the filament at a higher temperature and (2) by using krypton in place of argon as the inert gas filling the bulb. The increase in illumination by making these two improvements may be of the order of 25 per cent.

Cap Lamps

Information kindly supplied by the Ministry of Fuel and Power shows that 299,417 electric hand lamps and 170,292 cap lamps were in use on June 30, 1946. It is interesting to note that in 1932 the figures were, hand 366,894, cap 24,248.

indicating the greatly increasing popularity of the cap lamp. In spite of this increased popularity there is still some prejudice in certain districts against the use of the cap lamp. Many miners prefer to have a source of light which gives a general illumination rather than a beam covering a limited area. Since the illumination given by the latest form of cap lamp is so superior to that given by even the most modern hand lamp, and bearing in mind also the advantages in respect of weight and freedom of movement of the hands, it is felt generally in mining circles that the use of the cap lamp should be encouraged. At the same time, makers of cap lamps should extend the range of illumination so as to enable the full angle of vision of the eye to be used. The illumination given by the beam should be graded, by means of a suitably designed lens or reflector, from a maximum in the centre of the beam to a minimum at the periphery, thus minimising the sharp contrast between beam and surrounding darkness.

Reference has already been made to the fact that the standard of lighting for factories is many times greater than the illumination given by the best of portable lamps. The coal miner is unfortunately not only handicapped by having a relatively poor illumination, but also by having to work in surroundings having an extremely low reflectivity. An object is seen by the light reflected from its surface. The lower the reflectivity, the more difficult it is to distinguish details in the object. The reflectivity of coal varies from about 3 per cent. to 12 per cent., an average being probably about 5 per cent. Assuming this figure, the coal on which the miner concentrates his attention with the help of a cap lamp beam averaging 10 candle-power, the lamp being at a distance of 2½ feet from the coal, has an average brightness of $10 \times \frac{4}{25} \times \frac{5}{100} =$ 0.08 candles per square foot. With a modern lamp giving 4 candle-power and hanging as it usually is, slightly further away, say, at 3 feet from the coal, the brightness of the coal is of the order of 0.02 candles per square foot.

It is of interest to note that the main conclusions of the Reid Technical Advisory Committee(1), in regard to underground lighting, were as follows:—

(i) "The standard of underground lighting is too low and reacts adversely on production, safety, and health. We consider that a standard of lighting of the order of 0.4ft.c. in the general working-area should be aimed at."

(ii) "As a source of illumination we regard the flame safety-lamp as obsolete."

(iii) "The required standard of lighting at the face is unlikely to be provided by hand or cap-lamps alone. A system of general lighting by power-fed lights supplemented, preferably, by cap-lamps, is necessary for this purpose."

(iv) "If electricity is permitted on the face, there is a *prima facie* case for permitting mains lighting also, subject to appropriate safeguards, which should be covered by General Regulations and not by Special Regulations in each case."

(v) "A higher standard of lighting should be provided out-bye on roadways."

It is well known, of course, that a certain amount of time is required for the miner to get his sight when he goes underground, and this is experienced in a marked degree when descending a pit on a bright summer's day. The illumination level required to eliminate eye strain on work of a class

normally undertaken by a miner is not really known, but the figure of 0.4 foot-candles suggested in the Reid Technical Report(1) as a minimum for coal-face illumination is probably of the right order.

Every endeavour should therefore be made to attain this degree of illumination and as much higher as possible. Under present conditions of coal-face operations, the realisation in practice of such a figure is not easy, and the committee was correct in stating that the attainment of such a standard with either hand or cap lamps in Safety Lamp mines is impossible. With portable lamps, either of the hand lamp or cap lamp type, the production of an increase in the candle-power-weight ratio is obviously of importance, as, of course, is also an increase in the lumens per watt. It is hoped that advantage will be taken by manufacturers of new light non-ferrous alloys and of plastics to reduce the candle-power-weight ratio, and that the possibility of the application of the fluorescent tube lamp to portable lamps will be fully explored in view of the fact that the lumens per watt for the fluorescent tube, with its relatively low brightness or glare effect, is roughly three times that for the tungsten filament lamp. Even if, with an appreciable increase in the candle-power-weight ratio, the illumination given by cap lamps may locally give the requisite illumination, the absence of general illumination is still a serious drawback.

Illumination at the Coal Face by Transportable Battery Lamps

Lamps of this category are the logical development of the miner's hand lamp.

Advantages (1) readily moved to where required;
(2) illumination of required standard can be given on work.

Disadvantages (1) weight and nuisance of having to transport daily for charging;
(2) difficult to obtain flame-proof certificate owing to emission of appreciable amounts of hydrogen when freshly charged;
(3) liable to be lost or mislaid at the working face;
(4) glare.

The idea of the coal face being illuminated by battery lamps other than the normal hand or cap lamps issued to each individual miner has not been received with much enthusiasm by the average colliery management. One of the main reasons for this is the shifting of the responsibility from the shoulders of the miner himself to some other individual. The use of relatively large battery lamps giving something of the order of 20 c.p., either for direct illumination or preferably for indirect flood lighting, has so far not had a thorough trial. A second reason is that the transportable lamps at present manufactured with flame-proof certificate are extremely heavy. There is a need for flame-proof equipment of this type in lightweight alloy.

Tests have been carried out at a Kent and also at a Warwickshire colliery with an 18 c.p. tungsten filament lamp (not yet flame-proof) in a 14-volt transportable battery lamp equipment. The lamps were used both for direct and floodlight illumination (i.e., altogether by reflection). Two miners on the face at the time were strongly averse to the use of the direct beam for illuminating the face, on account of glare, which admittedly was very troublesome. By light reflected from a whitish background of stone-dusted pack-wall, figures varying between 0.25 foot-candles and 0.1 (between lamps) were obtained on the coal face when two lamps were spaced six yards apart. This method of illumination was approved by the two men. Higher figures were obtained at Binley

Colliery when a pure white dust was used in place of the ordinary limestone dust. It was clear from these tests that by the use of a number of transportable battery lamps for floodlighting, the coal face could be more evenly illuminated than by a system of direct lighting, and although the brightness of the coal was not so high as with a direct beam, it was felt that this was compensated for by the additional visual comfort through absence of glare and by the removal of objectionable shadow effects.

In view of the importance of getting greatly improved illumination on coal face operations, it would appear to be worth while to try out properly organised and full-scale tests on 100 yards of face. Approximately 25 lamps would be required, and the transport of the lamps daily to and from the coal face would, of course, require proper organisation. An indication of the degree of illumination which may be obtained on the coal face has been given by the results obtained by this method of lighting on the model coal face at the Royal School of Mines. Where it is feasible to instal either electric mains or compressed-air lighting equipment, illumination by means of transportable battery lamps would not be advocated. The development of a transportable battery operating a fluorescent tube in place of a filament lamp would be of very great advantage.

Illumination of the Coal Face by Mains Lighting

Where electric mains are available at or near the coal face, lighting from this source of power appears to be the most promising. The history of coal face lighting from the mains has, however, not been encouraging either from the point of view of cost, ease of daily transfer, or in results achieved. In regard to cost, the ideas of the mining engineer have undergone a radical change in recent years. Efficient illumination of the coal face is now felt to be a necessity and not a luxury, and therefore an appreciable charge per ton of coal is viewed with equanimity, for such a system of coal face illumination enables cleaner coal to be obtained more efficiently, with greater safety and with less risk to health.

Lighting from the mains appears to have been first used underground at collieries about 66 years ago. In 1902, the carbon lamps used hitherto were replaced by tantalum and osmium, and later by tungsten filament lamps. The development of suitable plugs of a flame-proof character has obviously been an important factor in the application of electricity for lighting, and much work has been done by manufacturers and others, including the testing station at Sheffield, in the development of fittings giving a maximum efficiency in regard to light with the greatest degree of safety.

Although the lighting of pit bottoms, haulage, pump and switch houses has been practised for a good many years, it is only within the last two decades that illumination on main roads by mains lighting has become at all common. In 1930, Bestwood Colliery installed mains lighting for a distance of 1,100 yards along a main haulage road, and since then other progressive collieries have made similar advances.

Although coal face lighting from electric mains was tried in this country as long ago as 1881 at Pleasley Colliery, and in 1886 at Earnoch, lack of suitable equipment made these early experiments of little help to the industry. Over the next forty years little was done until, through the support given by Mr. J. C. Mitcheson, with the approval of his father, the late Mr. George Mitcheson, Messrs. Morris and Shaw, of Birch Coppice Colliery, installed in 1927, a 25-volt system with concentric cable and gas-filled 25 c.p. lamps, which were later replaced by metal filament tractor type lamps. This installation was in a thin

seam two and a half to three feet thick, which necessitated close spacing of lamps, and as a result the voltage drop at the end of the face was considerable. A second experiment was made with Siemens-Schuckert lamps at 125 volts from drilling transformers, in a seam five feet high, using 60 watt lamps (gas-filled). Considerable trouble arose through breakage in this case. The late Professor Cramp's system of combined plug and transformer was tried at Birch Coppice Colliery in order that the more robust 25 volt lamps might be used, but was discontinued owing to the weight and bulk of the apparatus.

A final trial was made with 125/15 volt transformers attached to each lamp, but this again suffered from the drawback of weight and the difficulty of placing so that the light would show where required.

The installation was abandoned finally owing to:—

(i) high costs due to (a) breakage of filaments;
(b) cost of labour for moving daily;
(c) unreliability of installation thus requiring provision of individual lamps.

(ii) lack of enthusiasm on the part of the men, owing to care of apparatus, uneven illumination, shadows and dazzle The men appeared to prefer the high power lamps just introduced.

(iii) difficulty in spacing lamps; more lamps increased "flitting" troubles and damage, fewer lamps accentuated inequality of lighting and shadows.

Up to 1934, the restrictions of Section 32 of the Coal Mines Act, 1911, and General Regulations 78 and 132 (iv) prevented the use of electric mains lighting at the coal face in safety lamp pits, although it could be used on a naked light coal face.

In 1934, these regulations, G.R. 78 and 132 (iv), and section 32 of the Coal Mines Act, 1911, were amended by the establishment of the Coal Mines General Regulations (Lighting) 1934, which permitted mains lighting in any face of a mine, subject to special regulations. The voltage was, however, still restricted to 125.

Other collieries which have investigated mains lighting have been Nunnery (1932) and Steetley (1934). At Nunnery Colliery a face 140 yards long was lighted by 125 volt 60 watt lamps spaced 5 yards apart, with a wander lead of three yards for each lamp, and the main cable divided into lengths of fifteen yards coupled by plug couplers. At Steetley Colliery one half of a double unit was at first lighted by means of 60 watt 110 volt lamps of special safety design evolved by Dr. Alsop in conjunction with the lamp manufacturers. In 1935, a second system was installed on the other half of the same face covering 130 yards. A three-phase supply was used and 25 volt 30 watt lamps were spaced five yards apart.

The conclusions drawn from the Steetley tests were that the improved lighting was reflected in a decrease in accidents, no reduction in dirt, but some increase in the rate of stripping and filling. The total cost over eighteen months was 0.7d. per ton with a saving in compensation of 0.3d. per ton. Nevertheless the system was discontinued owing to difficulties in the manufacture of special lamps.

More recently, face lighting from the mains has been installed at Rawdon Colliery on a face being stripped by a Meco-Moore cutter-loader. The seam was seven feet thick and the installation was on a face 100 yards long. Lamps of 25 watts in prismatic fittings were mounted on steel props in the waste side

of the conveyor at 25 feet centres with couplers at 50 feet. It was proposed, however, to increase the illumination by using 40-watt bulbs.

Mains Lighting in the Ruhr

In their technical report on the Ruhr coalfield(4), the mission from the Mechanisation Committee of the Ministry of Fuel and Power stated that illumination in the Ruhr mines is of a high standard. It is claimed in the Ruhr that the good illumination at the shafts and in the roadways "contributes to a higher standard of track maintenance, which, in turn, lessens breakdowns." Mains lighting is used extensively on the coal-face in the Ruhr, owing largely to almost complete absence of shot-firing. On the other hand, the mission concluded that the positive advantages of this form of lighting played a big part in its development. For mains lighting it is claimed in the Ruhr that good face lighting results in improved pneumatic pick performance, a quickening of face operations, and cleaner coal. It is further claimed that the accident rate is reduced and the health of the miners improved.

The illumination levels in the Ruhr mines, based upon practical experience, appear to vary between 0.5 and 7.5 ft.c. for all phases of underground lighting. The mission concluded that at the face, the illumination is seldom below 0.5 ft.c., often 1 ft.c., and sometimes 2 ft.c. About 74 per cent. of the face and gate road lighting is at 220 volts.

The arrangement of cables and fittings is more or less standardised by splitting into sections of about 80 feet in length, each section containing four or five lamps, usually of 40 watts, and 16 to 20 feet apart. On occasions, 60-watt lamps spaced at about 33 feet are used. The 80 feet sections are connected by means of four pin plug and socket couplers, which usually include a push-button switch for signalling purposes. Signals to stop and start face conveyors or other remotely controlled face equipment are made according to an established code.

It was stated that the prevention of glare has been the subject of much research. Opal glasses with or without opal or pearl lamps have been found best for preventing dazzle. It is claimed that in the latest form of well glass the light loss is only 8.5 per cent., against 40 per cent. loss in types previously employed.

In regard to roadway lighting in the Ruhr, it is not uncommon to find mains lighting of high standard on roadways two miles or more in length. The proportion of electrical energy used for lighting underground workings is relatively high and puts Great Britain in this respect in a very unfavourable position. At the Jacobi Mine (output 5,000 tons per day) the electrical energy used for lighting underground is stated to be 15 per cent. of the total consumption. Nearly 2,000 lamps are in use underground, 1,000-watt lamps are used around the shafts, 300-watt lamps are spaced 16 yards apart for a considerable distance along the main roadways, and 200-watt lamps at 22-yard intervals up to gate roads. On gate roads up to the face 100- or 60-watt lamps are used at 6-yard intervals. On the faces 60- or 40-watt lamps are used at 4½- to 6½-yard intervals.

Mains Lighting in Other Countries

Holland has applied mains lighting extensively underground, but not probably to the same extent as Germany in regard to coal face lighting. In Belgium and France the practice appears to be to use the latest type of hand lamp, whilst American practice seems still to be completely attached to the

cap lamp of high power, together with flood-lighting where power loading is used.

The report of the Mine Lighting sub-committee points out that the history of coal-face lighting is one of successful experiments, abandoned after limited trials owing to the failure of each new installation to produce the expected increases in economic advantages. In several trials, reduction in the number of accidents is acknowledged, but, in spite of this, the frequent breakage of lamp bulbs and well glasses and the additional labour charges for disconnecting, moving forward, and reconnecting before every coal-turning shift, have continued to militate against extension of this form of face illumination.

The reasons for the more successful use of mains lighting in Germany in particular seem to be due to several factors:—

(1) absence of shot-firing,
(2) appreciation of need for better lighting and willingness to accept the assistance of a high standard of lighting as a legitimate charge on output and as an economic necessity.
(3) greater docility on the part of German miners to accept without question whatever is installed.

Lamps for Mains Lighting

Tungsten Lamps

Little more need be said concerning the filament type of lamp bulb, except to point out that any further attempt to increase output of lumens per watt appears possible only at the sacrifice of length of life, or by the use of krypton, as is done in miners' lamp bulbs.

Vapour Discharge Lamps

The advent of the vapour discharge lamp has removed some of the drawbacks inherent in the tungsten filament lamp. Although the initial cost of discharge lamps is very much greater than that of tungsten filament lamps, the life is very much longer and, furthermore, being more robust, they stand much rougher treatment.

The chief characteristics of the different types of lamps now available have been listed in the report of the sub-committee on Mine Lighting. It is shown that with the normal capacity up to 150 watts the initial lumens per watt for tungsten filament lamps are about 11.5 to 14.0, whereas mercury vapour discharge lamps vary from 34 to 43 lumens per watt and sodium lamps from 38.5 (45-watt) to 60.5 (140-watt).

Mercury Vapour Lamp

The light flux given by the discharge of electricity through a gas varies greatly with the pressure. In mercury vapour, the illumination increases with pressure, the predominating lines of the visible spectrum being in the yellow (5776.A), green (5461.A), and violet and indigo (4047 and 4358.A).

The mercury discharge lamp thus gives the well-known bluish green colour, to which many people object on aesthetic grounds, but which nevertheless appears to make it easier to distinguish between materials such as coal and shale.

Sodium Vapour Lamp

When first switched on, the illumination is low, but after 15 minutes full output is obtained. Owing to the monochromatic colour of the light, discrimination in colour of objects is poor. Moreover, there are certain dangers owing to the inflammability of the sodium, should a bulb be broken

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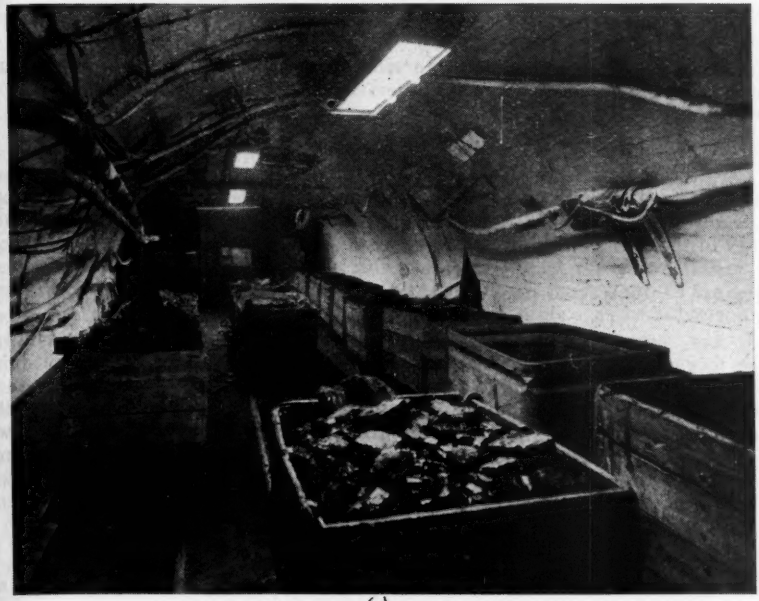

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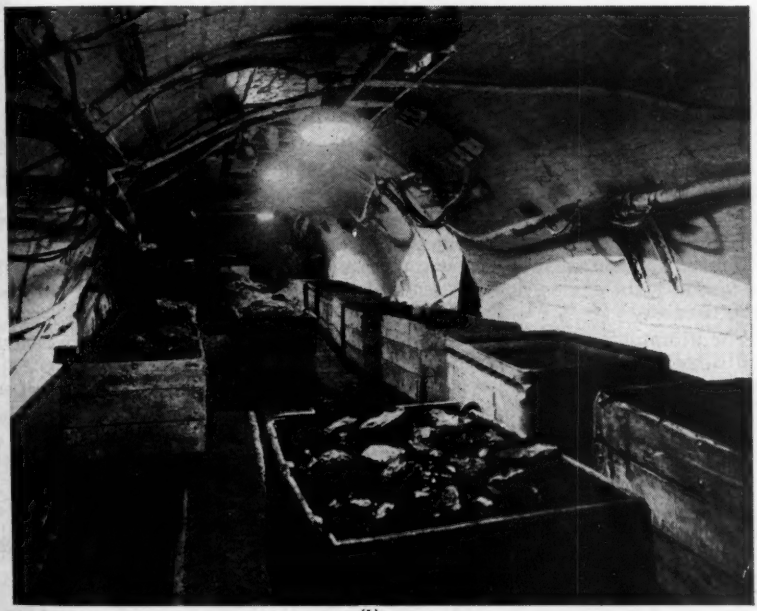


(b)

Fig. 1. Illustrating difference between illumination of Binley Colliery Pitbottom by means of *(a)* Fluorescent-tube Lamps and *(b)* Tungsten-filament Lamps *after* whitewashing.

underground. On the other hand, in a dusty or misty atmosphere the sodium lamp has an appreciable advantage over the mercury vapour lamp.

Fluorescent Lamps Suitable for Mining Operations

Certain materials have the property of changing spectral energy of one frequency to radiation of a lower frequency. Such materials are described as "fluorescent." This property is of particular value for converting the energy in the invisible or ultra-violet part of the spectrum into visible radiation. The visible radiation from a mercury discharge lamp may thus be increased by the aid of fluorescent materials inside the bulb, and a mixture of fluorescent and normal discharge light obtained.

It has been found, however, that the most effective conversion of ultra-violet to radiation in the visible spectrum may be obtained by utilising the strong spectral line of mercury at 2537Å, obtained by discharge at low pressure. This fact is made use of in the modern fluorescent tube lamp. Without the fluorescent powder, practically no radiation is visible. It is now well known that different minerals give different colours when exposed to the same source of ultra-violet light, so by employing suitable chemical compounds or mixtures, light of almost any desired colour can be obtained. The most popular colours are "north daylight" and "warm white."

The advantages of fluorescent tube lighting in mines are:—

(1) psychological effect of daylight,
(2) high efficiency, 35 lumens per watt,
(3) low brightness, 3 candles per square inch,
(4) tubular lighting correct for mine services,
(5) longer life,
(6) with voltage changes, fluorescent lamps are only slightly affected,
(7) delay in relighting inappreciable,
(8) Intrinsically safer than tungsten filament lamps.

Installation at Binley Colliery Pit Bottom.—This installation is of interest since it is the first occasion on which flameproof fluorescent equipment has been installed in a coal mine.

An account of this has been given in B.C.O.R.A. Bulletin (No. 9, March, 1946), but it may not be out of place to give some details to this Society.

Four 5 foot 80 watt lamps were spaced at 18 feet. The one nearest the cage was at right angles, and the remaining three were parallel to the direction of the roadway.

The illumination given was found to be 18 foot-candles immediately beneath the fittings and 2 foot-candles between the lamps. Fig. 1 shows the effective removal of shadows with fluorescent lighting, where white washing of roof and sides of the roadway has been carried out.

Application of the Fluorescent Tube Lamp to Mains Lighting at the Coal Face

The advantages possessed by the fluorescent tube lamps for coal face lighting have been enumerated above. More than a year ago, one large firm of manufacturers was persuaded to develop a lamp suitable for coal face lighting. The experimental form was shown in the model coal face in the

Fig. 2. 15 watt, 18 inch fluorescent lamp and experimental flameproof fitting as installed at Birch Coppice Colliery.

laboratories of the British Colliery Owners' Research Association at an exhibition of mine lighting arranged for the Institution of Mining Engineers in February, 1946. A set of ten lamps has been installed at Birch Coppice Colliery for some time. This employs the 18 inch fluorescent lamp, in an experimental flameproof fitting, as shown in Fig. 2, spaced at 8 foot intervals. Another experimental installation near the pit bottom employs 24 inch 20 watt lamps fixed transversely to the direction of the road. It is a matter for discussion as to whether they should be placed parallel to the roadway in order to minimise glare, although admittedly this is very slight.

The report of the sub-committee on Mine Lighting of the N.I.C.(2) was submitted to the Institution of Mining Engineers in February, 1946. In this the advantages to be derived from the application of fluorescent lighting at the coal face are stressed. In the spring of 1946 the Ministry of Fuel and Power appointed a sub-committee of the Mechanisation Committee to examine the possibilities of using fluorescent tube lighting in the coal face. The committee is under the chairmanship of Mr. R. Crawford, and membership covers various interests, including manufacturers, and colliery electrical engineers and a representative from the Scientific Department of the National Coal Board (late B.C.O.R.A.).

An appreciable sum of money has been allocated to enable different systems of lighting to be tried out. Much of the time of the Committee has been taken up with design of suitable flameproof lamps, couplers, and other equipment. In the near future it is hoped to equip at least one coal face in each of eight different collieries in various regions.

Various criticisms have been made against fluorescent lamps, one being the stroboscopic effect. This can, however, be easily obviated.

It will thus be seen that application of what is so far the best system of illumination for mining conditions is now being tackled on a proper scale. It is hoped that the various difficulties which have been encountered with other forms of mine lighting may be overcome. One of these is present legislation. The Reid Committee's report(1) stated that there was a *prima facie* case for permitting mains lighting provided that "permission to install electricity in the face should include its use for lighting from the mains, subject to proper safeguard, and should not have to be the subject of special regulations for each installation as is now the case."

The Pneumatic-Electric Lamp

In spite of the active work now in progress for the installation of mains lighting, mining conditions in many pits, particularly in regard to gas emission, may not permit the application of this form of lighting even with relaxation of the present regulations. Such pits, if equipped with compressed air, have in the pneumatic-electric lamp, as pointed out in the Reid Report(1), a means already at hand for greatly increasing the illumination at the coal face. The idea of a self-contained lamp and generator worked by compressed air was covered by patents taken out about fifty years ago, but nothing was developed until Mr. H. S. Potter, a South African mining engineer pointed out that an equipment of this description could be made practical by the employment of some of the new light-weight alloys and steels. The first flame-proof unit, made in 1922, gave a voltage of 12 and employed a 36 watt bulb. Improvement in cobalt steels enabled the output to be increased to 60 watts with a voltage of 25. The lamp was approved as safe for use under all conditions.

For the next ten years or so after its introduction the lamp was in demand to give the better light required at loading points and junctions, but no

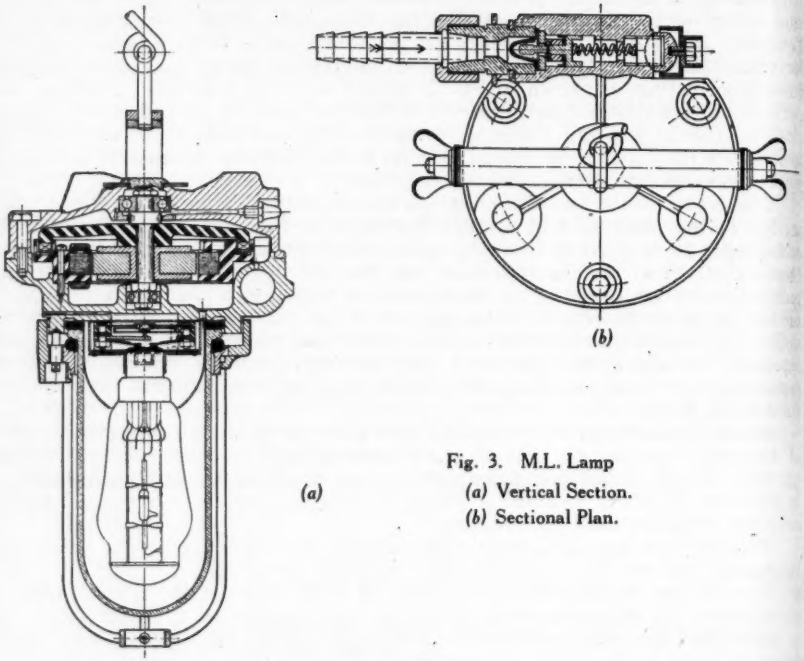


Fig. 3. M.L. Lamp
(*a*) Vertical Section.
(*b*) Sectional Plan.

application to coal face lighting was made until Mr. T. C. Maynard (5) equipped a length of coal face in a North Staffordshire pit with 40 lamps.

Several modifications of this type of lamp are now in production in this country. One such lamp (Fig. 3) is a self-contained unit which is capable of functioning satisfactorily when connected to any compressed air supply giving a pressure of 40 lb. per square inch. The lamp consists of a strong metal casing containing a turbine, operated by compressed air, and revolving field alternator, the latter being fitted inside the turbine wheel. The compressed air first passes through a filter, and thence through a reducing valve to bring the pressure to approximately 40 lb. per square inch before passing to the turbo blades. After leaving the exhaust side of the turbine, the pressure of the air is still maintained at 2 to 3 lb. per square inch in excess of that of the atmosphere into which it escapes via an airscreen arrangement around the wellglass to prevent dust and dirt collecting thereon. Some of the exhaust air scavenges the inside of the wellglass and eliminates the possibility of collection of firedamp. A safety device, in the shape of a spring loaded diaphragm is incorporated to ensure that the lamp can only be lit when the atmosphere within the wellglass is at the requisite pressure.

Two types of this lamp are available, one giving 36 watts and the second 60 watts, whilst another design, differing somewhat in detail, gives 50 watts at 6 volts. As will be described later, a vast improvement in the output of light for the same air consumption has been achieved by replacing the tungsten filament bulb by a small 40 watt mercury vapour discharge lamp. This involves

altering the generator to give the necessary striking voltage of approximately 100, and a running voltage of about 70. The light given by this modification is about 1,500 lumens.

Cost of Coal Face Lighting by Means of Pneumatic-Electric Lamps

The experience of four years with pneumatic-electric lighting at Norton Colliery on four different faces enabled the authors of the paper quoted [5] to estimate with a fair degree of accuracy the average cost of the coal face illumination. This was 0.47d. per ton of coal, taking the cost of compressed air at 0.766d. per 1,000 cubic feet (free air). The lamps were spaced 6 to 6½ yards apart and hung 2 feet below the roof. The thickness of the seam was 7½ feet and, when the face was idle, the average illumination on the coal face was 0.8 to 1.0 ft.c. for the minimum distance of 4½ feet from the face, and 0.35 ft.c. for the maximum distance of 8 ft. During coal cutting operations, dust in the atmosphere reduced these values to 0.5 ft.c. and 0.1-0.2 ft.c. respectively. It is of interest to note that earlier tests in the Holly Lane seam had to be discontinued on account of bulb breakage resulting from shot firing and the removal of equipment.

Other investigations with the compressed air lamp for coal face lighting

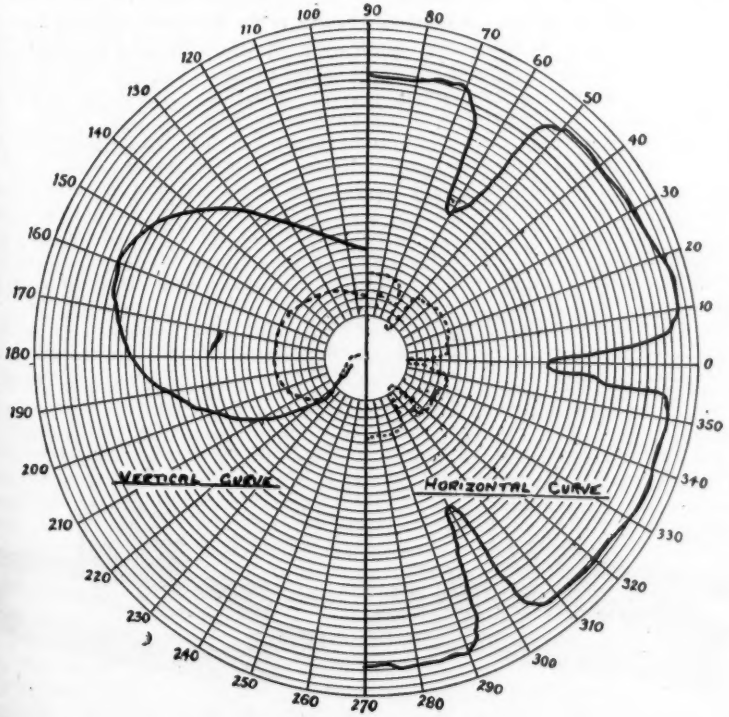


Fig. 4. Comparison of the polar curves for the 36-watt tungsten filament M.L. lamp *(dotted line)* and the 40-watt mercury vapour M.L. lamp *(full line)*.

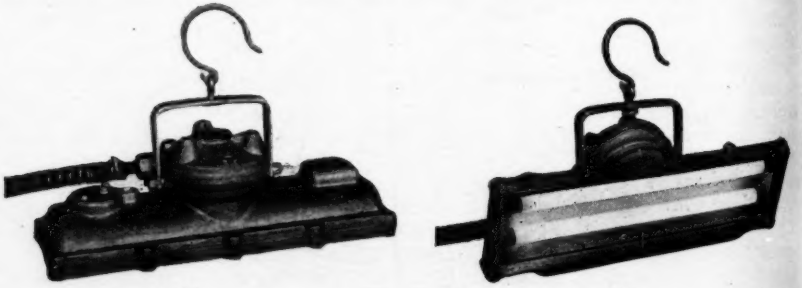
were made at Langwith Colliery and at a Yorkshire pit. At the former the cost per ton worked out at 0.92d. with an inbye compressor. The cost of compressed air was the chief charge in determining the cost per ton, and figures for this have been found to vary between 0.4d. and 3.5d. per 1,000 cubic feet, with efficient compression and distribution. The overall cost of maintenance, including hose replacement, at the Yorkshire Colliery referred to above, worked out at 1d. per ton of coal with compressed air at 3.5d. per 1,000 cubic feet, the cost of the compressed air being in this case 50 per cent. of the total charges.

In 1938, the number of compressed air lamps in use in this country was approximately 2,000, whereas fifteen times this figure were in use in Germany. The extent to which they were in use for coal face illumination is not known, but undoubtedly a large number must have been used for the purpose. In Great Britain, in spite of the pioneer work in North Staffordshire, the number of coal face installations is not high. This is due to several causes. Firstly the cost of compressed air, secondly the nuisance of moving forward equipment daily on a mechanised face, and thirdly the lack of appreciation by men and management of the advantages of increased illumination. Another cause will be referred to later, namely the nuisance of glare or brightness contrast between the source of light and its background.

Application of the Vapour-Discharge Source to the Pneumatic-Electric Lamp

The writer's interest in the application of the vapour discharge lamp to underground illumination and the steps taken to make this interest of practical value have been indicated in a paper in the technical press some years ago(6). The development in 1936 of a small 40-watt mercury vapour lamp capable of operation on a 100/130 volt circuit rendered possible the application of this form of lighting to underground conditions. The marked increase in light output over the tungsten filament lamp makes the new lamp a better practical proposition in spite of the greater cost of bulbs. It is estimated that the overall reduction in cost should be between 0.1d. and 0.2d. per ton of coal depending upon the cost of compressed air. Comparison of the polar curves for the 36-watt tungsten filament and the 40-watt mercury lamps is shown in Fig. 4 which illustrates the marked superiority of the mercury vapour lamp.

A drawback of this lamp is, however, the time taken for relighting should the compressed air supply be cut off momentarily or the pressure reduced below that necessary for the generator to function. The lamp, when cold,



(a) *(b)*

Fig. 5. Pneumatically operated lamps using twin fluorescent tubes, *(a)* showing the top of the lamp, *(b)* showing the lamp lighted.

lights as soon as the generator is running sufficiently fast to develop the required voltage, usually only a few seconds after turning on the air supply, although it takes several minutes for the full light intensity to be attained. If, however, the arc is broken by reduction of air supply, three or four minutes may elapse before the arc re-strikes.

Pneumatic-Electric Lamps with Fluorescent Tubes

In the report of the sub-committee of the N.I.C. on Mine Lighting, attention is drawn to the possibility of using suitable fluorescent tubes in pneumatically operated lamps. Such a lamp has now been produced, using twin fluorescent tubes as illustrated in Fig 5. The disadvantage of delay in relighting after a temporary interruption of the compressed air supply is eliminated in this model. For the same air consumption an output of approximately 1,000 lumens is obtained with light of a pleasant colour, having none of the aesthetic disadvantages of the ordinary mercury vapour lamp.

There is at the present time a real need for this, and it will be agreed that the lamp illustrated is a piece of craftsmanship for which the mining industry should be grateful.

Glare

The new regulations relating to mine lighting state that "so far as reasonably practicable, the lighting shall be so arranged as to prevent glare or eye-strain."

This is almost the most important side of mine illumination, and involves the reduction of shadow contrasts and of glare. The two are to some extent interdependent. Glare is the contrast between source of light and its background. The more nearly the source of light approaches to a "point," or, in other words, the greater the brightness per unit area of light source, the greater the glare; hence the use of pearl and frosted or opal lamps to spread the bright area. With fluorescent lamps the source is spread over a still wider area with a brightness figure of approximately 3 candles per square inch, which can be viewed with relative comfort and a feeling of absence of glare, as against a figure of 130 candles per square inch for a 60-watt pearl lamp.

With conditions of low reflectivity, as at the coal face, every effort should be made to employ light sources with minimum brightness. This means that the light must come from a wide area which automatically reduces shadow effects.

It is well known and appreciated that the whitening of the roof and sides of the mine roadways makes a tremendous difference to visual comfort and apparently increases the illumination. The proposed lighting regulations make compulsory the whitening of certain specified places of permanent or semi-permanent character, but the coal face is not included. However, everything possible should be done to ensure the maximum reflectivity at the working face by the painting or whitewashing of all plant and materials used thereon. Local whitening with stone dust or other material in the vicinity of, and as a background to, the source of light should also be practised. B.C.O.R.A. investigators (now under the National Coal Board) have been, and are, investigating this subject and the possibilities of various materials.

Conclusion

In this paper an attempt has been made to indicate the present position of underground lighting and the experimental work now in progress to improve the standard of lighting at the coal face. It is generally agreed by mining engineers of authority that for the satisfactory economic development of the

coal mining industry, as well as for the well-being of the workers engaged therein, improvement in underground lighting and, in particular, illumination of the miner's work at the coal face are matters of fundamental importance. The advantages of improved lighting cannot be assessed directly in monetary value either through increased output, clean coal, or even in terms of the elimination or reduction in the incidence of miner's nystagmus. Increased safety, higher efficiency, and psychological effects of great importance, which would influence the flow of recruits to the mining industry, will, it is believed, follow from better lighting of the coal face, of haulage roads, and of any part of the mine where human labour is employed.

From these experiments it is hoped that a new era in coal face lighting will result.

The author wishes to acknowledge his indebtedness to the following for permission to reproduce the figures:—

The Institution of Mining Engineers for Fig. 1.
The South Wales Institute of Engineers for Fig. 4.
The British Thomson-Houston Co., Ltd., for Fig. 2.
Messrs. John Davis and Son (Derby), Ltd., for Figs, 3 and 5.

References

(1) Ministry of Fuel and Power. Report of the Technical Advisory Committee on Coal Mining. (Reid Report.) (Cmd. 6610).
(2) Report of the Sub-Committee on Mine Lighting of the National Illumination Committee. Trans. Inst. Min. Eng. 1946, Vol. 105, part 7, pp. 332-383, and part 12 pp. 708-710.
(3) The Candle-powers of Safety Lamps Before and After Underground Shifts, by T. David Jones, Ph.D., M.Sc., and C. E. Morgan, B.Sc., Trans. Inst. Min. Eng. 1931, Vol. LXXXII, part 1, pp. 43-104.
(4) Technical Report on the Ruhr Coalfield by a mission from the Mechanisation Advisory Committee of the Ministry of Fuel and Power. B.I.O.S. 394, Vol. 1 (H.M.S.O.).
(5) Lighting in Mines: Coalface Illumination by Means of Compressed Air Electric Lamps, by T. David Jones, Ph.D., M.Sc., and T. C. Maynard, M.C., D.C.M. Trans. Inst. Min. Eng., Vol. XCI, pp. 311-322 and 338-339.
(6) Applications of the Vapour Discharge Lamps to Underground Lighting, by J. Ivon Graham, M.A., M.Sc., Colliery Engineering, November 1938, Vol. 15, pp. 363-367.

Discussion

Mr. R. Crawford (Electrical Engineer, National Coal Board) said Mr. Graham's paper was a very complete progress report on underground lighting to date, and not only indicated all that had been done in the past but gave some very clear indications of what could and must be done in the future. Mr. Graham had quoted from the first sentence of paragraph 520 in the Reid Report, and he would like to add the remainder of that paragraph, viz., "No man can work properly without good light, and this is especially so in the mine, where conditions are difficult. It is not easy to provide safe and satisfactory artificial lighting underground, and while recently the standard of illumination has considerably improved, more particularly following upon the Lighting Regulations of 1934, there is still much room for improvement." In the past, far too many attempts had been made to introduce mains lighting underground without the least scientific basis, including the application of standard industrial lighting equipment, more or less ad hoc. These attempts were doomed to failure from the start, and apart from the very few special installations to which the author had referred, nearly all had failed. Such results were not surprising because in no case, so far as he knew, was a competent illuminating engineer

invited to go underground to see the conditions which the industry was asking him to meet. In fact, to put it somewhat crudely, it was more often than not left to salesmen to sell the colliery the necessary fittings, string them together with a piece of cable and place them underground. That was surely no way to tackle a really involved scientific problem.

He had been impressed during his visits to Germany with the success of mains lighting underground, both on the roadways and at the coal face. It had been claimed that that was due to the fact that they did not use explosives at the face and that therefore there was not the same risk of damage to fittings and cables as might happen in this country, but he did not take the view that we should allow this practice of shot firing to prevent the development of a safe and satisfactory system of face lighting. Designers should be able to provide fittings which would stand up against the normal effects of shot firing. He believed that in the fluorescent lamp there was a chance of reviving interest in face lighting. It was still a novelty, but if they could interest the miner in it and get it installed it might put an end to the difficulties of the past. It was the right type of lamp and the right shape, and would work under wide variations of voltage, whereas the old traction type lamp often suffered seriously due to excessive voltage drop, and more often than not just glowed.

The pneumatic electric lamp would be very useful in mines where electricity could not be used, but it was a type of lamp which he was not sure would be very popular here. It had been adopted in some of the German mines. He could see objections to the compressed air-driven turbine driving a small generator and from that generator using mains lighting at normal voltage. In most of our mines where compressed air was used we could not use electricity because of gas. Perhaps the author would give his views on that. Although it might be rather rash to say so, he believed that more harm was done, and would be done, by having too little light underground than too much. He had seen one mine in the Ruhr where they had 150-watt lamps spaced 8 ft. apart. They were pearl lamps in opal well glasses, and therefore there was little glare or shadow. Some people might think the face was too well lighted. Personally he did not think they would succeed in face lighting until the roadways from the shaft to the face were also lighted. Perhaps the cages also should be lighted so that men going from sunshine at the surface to the face would not have to go through long periods of darkness or very poor lighting. The men must be given light the whole way from the surface to their work.

Mr. W. J. JONES, remarking that he recalled some of the early experiments in the lighting of the coal face, said that if these installations had been planned by an illuminating engineer they would probably have been more successful. He gathered that the miners were disgruntled with the nuisance value and annoyance of the installations, but the Germans, in their methodical way, had educated their miners to the change. One of the important aspects of this problem was glare, and the advent of the fluorescent lamp would remove this difficulty. However, until the fluorescent lamp was generally installed for mine lighting, he suggested that the National Coal Board should look into the question of standardising the number of bulbs used for miners' lamps. There were over 60 different types of miner's electric lamp bulb, and he suggested that this could well be reduced to, say, 4. The ideal was that there should be one rating of bulb, one cap, one finish, and one diameter of bulb for a given size of battery, and, he believed he was right in saying, that could readily be accomplished with

four bulbs at the present time. Of course, the long-term plan was the fluorescent lamp, but the intermediate-term plan was that there should be a limited number of lamp bulb ratings.

Mr. F. WIDNALL said his interest in this matter had largely been confined to the fluorescent lamp to which he pinned his faith for mine-lighting purposes. Lighting in mines was something of a challenge to the lighting engineer. It was deplorable to have 0.4 ft.c., but when the figure went down to 0.05 ft.c. we got back to A.R.P. lighting, and those who had had experience of that above ground could readily appreciate what it must be like underground. Were there any figures available with regard to glare because the absence of glare was one of the advantages of the fluorescent lamp. It gave a source of relatively low brightness which was important both at the face and on the roadways. The mounting height was rarely more than 8 ft., and sometimes it was 6 ft., and when one looked at a row of 6, 7, or 8 ordinary 40-watt bulbs in well glasses, there was great disability glare. He had always found the glare due to low-mounted fittings in coalmines to be very troublesome. Indeed, the same applied to the cap-lamp at the face because every time a miner turned his head, his neighbour had a glare source directed straight into his eyes.

He emphasised the importance of white-washing, particularly on the roadways, and, commenting on the author's reference to the experimental installation at the Birch Coppice colliery and the question of mounting the lamps across or along the road, he said that from the illumination point of view there was no doubt that the lamps should be mounted across the road. That gave the minimum diversity between fittings. There were a number of mechanical considerations to be borne in mind in this connection, as well as the reduction of glare, which favoured mounting the lamps along the roads. It would be a matter to be determined in individual cases taking into account the mechanical considerations. Some people might prefer to have the lamps along the road because of these mechanical considerations.

Although the author had said that the new lighting Regulations came into force on January 1, he believed that in actual fact they were still in draft form. The possibility of raising the permissible voltage from 110 to 220 as indicated in the draft Regulations would be helpful on account of the voltage drop over long lines when there were a number of lamps on one system.

Mr. S. W. RICHARDS said that whilst he appreciated the fluorescent lamp, he thought the tungsten lamp would remain in use for some time.

The hand lamp must be regarded as a passing phase, and in the course of a few years this type of lamp would be used simply and solely as a means of enabling the miner to get in by the working face. Nevertheless, he hoped it would not be long before mains lighting was available in mines. The hand lamp or cap lamp had nearly reached the summit of its usefulness, as there was a limit to the weight which a miner could carry which affected the amount of light available. Mine lighting must be divided into coal-face lighting and roadway lighting. In the case of the latter there was a tremendous future for the fluorescent lamp, which was still in an experimental stage as far as face lighting was concerned and where there were certain physical factors which militated against its use at present. There were coal faces 3 ft., 4 ft., and 5 ft. high, and in such cases the portability of the lighting unit had to be considered. Flame-proof enclosures for the fluorescent lamp would naturally be rather heavy, and whilst he agreed with the general advantages of the fluorescent lamp, which had been mentioned and were well known, we had not yet been able to

remove the danger of igniting gas, even with fluorescent lamps, although this might be overcome by future developments.

Some of the graphs used by the author showed a very pronounced peak form. In one case the peak went from 0.5 to 1.7 ft.c., but it would be agreed that in lighting the face a reasonably even lighting was required, otherwise there would be alternate light and dark regions.

Mr. J. W. HOWELL said that coming from a mining area, the paper was of particular interest to him. Referring to disability glare, he said a great deal of research was still necessary if the miners were to be given the full benefit of the light it was hoped to project on the coal face. There was also disability glare from the miner's cap lamp, as had already been mentioned, not only to other miners when one man turned his head at the coal face, but it was also distressing at times to anyone coming along the haulage-way. He believed that the ultimate lighting in mines would be mains lighting up to the coal face, although there were economic limits which would decide the question in the case of shallow seams of which there were many in the North of England.

In the draft regulations, figures were given for the maintenance of lamps which was an important matter. There had been cases in which lamps, brought off a shift, had given an illumination which was practically negligible. Now, however, 60 per cent. of the initial efficiency was required and that would certainly improve the lighting which the miner had at the face.

In the Reid Report, 0.4 ft.c. was the recommended illumination at the face. Although it was hardly possible to compare American conditions with ours, a comparison could be made with German practice. In that case the illumination was as much as 2 ft.c., and therefore he suggested that we could go well above 0.4 ft.c., with benefit to all concerned, provided appropriate safeguards were taken to minimise excessive contrasts. Some idea of these contrasts could be gained by reference to a paper before this Society, "Trans. Illum. Eng. Soc. (London)," Vol. 2, No. 3. March, 1937. He enquired if the author had any information regarding research on colouring walls apart from dead white. He knew that Major Platt agreed there was room for research on this problem. Dead white gave such heavy contrasts and it might be that off-white would offer advantages.

Referring to miner's nystagmus, we were told that this was probably caused (1) by glare, particularly where miners had to work on their backs at thin seams with excessive contrast between the brightness of the light source and its background, and (2) through looking upward into the light source, which caused the eye to take on the peculiar characteristic which resolved itself into nystagmus. He felt that the use of sources of lower surface brightness would decrease that tendency.

He was surprised to hear from Mr. Richards that the danger of ignition of gas by the fluorescent lamp had not been overcome. He had been given to understand that fittings had been developed, housing these lamps, which conformed to the requirements of Buxton specification.

Finally, he said that one of the greatest drawbacks to any innovation in mines was the conservatism of the miners, but one of the most valuable things which the National Coal Board had undertaken was the training of miners at the Staff Training College at Nuneaton where they were being trained in lighting and its application. That would be of the greatest benefit to the miners. He

knew the miners felt they were now getting something which they could understand and were evincing considerable interest in the subject.

Mr. L. T. MINCHIN asked if the author could say what was the principal visual task at the coal face, because that seemed to be the missing link in the paper. Were there one or two tasks that could be isolated as being representative of the kind of work the men were doing which would give a clue to the kind of lighting which should be provided.

Dr. A. G. WITHERS (National Coal Board) said that objects are discernible by reflection or contrast. Reflectivity at the coal face is generally very low and normally there is not much contrast between the exposed surfaces. Increase in intensity of the sources of illumination, without regard to their distribution or the nature of the surroundings, may give rise to serious problems of glare.

Several aspects of coal face "mains" illumination, as distinct from the lighting of mine roadways, call for the closest co-operation between illumination expert and mining engineer. Full appreciation of the particular difficulties involved should go far towards facilitating a broader approach to the problem. In this connection, he said, it may not be out of place to indicate briefly what are felt to be some of the more outstanding considerations. These are:—

(1) The need for a suitable technique for the measurement of reflected light intensity at the coal face, with a view to the basing of statutory standards on such a form of measurement.

(2) The desirability of providing adequate illumination of the roof and floor, as well as the coal face, and the elimination of excess shadow effect.

(3) The treatment of surfaces—in particular the floor, roof, supports and pack walls—by simple effective means to provide a minimum standard of reflectivity.

(4) The elimination of air-borne dust—a matter of vital importance in relation to the adequate illumination of intensively mechanised faces. Excess dust deposition effectively reduces illumination at the face by persistent coating of reflecting surfaces and lamps.

The last two considerations, he said, are no doubt being given the closest attention by those bodies engaged in the study of mine lighting.

Mr. T. J. SACH remarked that the author was in error in saying that miners' lamps were filled with neon. Argon was used, and in future it would be krypton. Continuing, he said he did not think the author had stressed sufficiently the effect of poor illumination on miner's nystagmus. Various committees had considered this question under the Medical Research Board and were almost unanimously of the opinion that it was primarily due to very poor illumination. He had got out some figures before the war which showed that as the light output of miners' lamps increased in the course of years, so the incidence of miner's nystagmus had gradually decreased.

Mr. A. G. PENNY, referring to the intrinsic safety of the fluorescent lamp, said the essential point was that the risk of explosion from this type of lamp came from the heated electrodes. Tests had been carried out which showed that under normal running conditions the temperatures at which the electrodes operated were insufficient to cause explosion. The ordinary method of starting

the fluorescent lamp was to pass a current of approximately twice the normal running current through the electrodes, and the resulting temperature, apparently, was just enough to cause explosion. It might be assumed that this risk was not very serious since the period of starting was only a few seconds, but if the lamp was broken and did not fall from the holders, the starting switch would still continue to try and operate the lamp until one of the electrodes burned out and disrupted the circuit, causing an arc and an explosion. Therefore the risk is greater than appears at first sight, and it could not be said that the fluorescent lamp was intrinsically safe; but there was a possible solution to the problem. In his early experiments before the war, Major Platt found that in cold cathode lamps, although they dissipated more energy at the electrodes than a hot cathode lamp, the electrodes ran at a lower temperature and did not fire the gas. Such lamps are started by the open circuit voltage of the stray field transformer, which is normally used to stabilise them so the electrodes never exceed their running temperature.

The objection to the cold cathode lamp was that the over-all efficiency was of the same order as the filament lamp, and that with the higher cost of gear and the higher voltage, they did not appear to be very attractive commercially.

However, it might be possible to combine the merits of hot and cold cathode electrodes by using electrodes which would start cold, and then would run hot, with the lower wattage losses of the hot cathode type, thus getting the greater luminous efficiency obtained from hot cathode lamps. The idea of lamps that started cold and ran hot had not been put to a practical test in this country, but as soon as some such lamps had been made it was intended to try them out and see whether, in fact, practice bore out theory. Personally, he thought it would do so, and he was supported in that idea by the experience of Americans who had carried out a few preliminary experiments on cold-starting and hot-running cathodes, which suggested that they were intrinsically safe. If that were so, there was every possibility that the fluorescent lamp could be considered very much safer than the filament lamps, and considerably more attractive than, perhaps, some people thought, at the moment.

Mr. J. G. HOLMES said that the daylight colour of fluorescent lighting is suggested to be an advantage, but it is general experience above ground that a warmer colour is preferable at low levels of illumination. Moreover, the paper stated that the soft light of flame-lamps, with a brightness of, perhaps, 5 candles/sq. inch, was preferred to the light of electric lamps, the brightness of which may be as low as 2 candles/sq. inch for diffusing glasses, and it seems that a case could be made for the use of a fluorescent lamp with powders chosen to give a yellowish light. The use of a lower colour-temperature would reduce the effect of after-images and would enable the eyes of the miner to operate in a condition more closely approaching dark adaptation. It seems possible that these advantages would outweigh the slight loss in the efficiency of the lamp in terms of lumens per watt.

In describing the opal glasses used in the Ruhr coal-fields, the author implied that there is a German glass with a light loss of only 8.5 per cent. compared with a loss of 40 per cent. in the glasses generally used. Whilst he did not question these figures, he pointed out that the loss of light is due primarily to the metal work of the lamp and the absorption of light in the glass itself is usually of the order of 8 per cent., and very rarely exceeds 15 per cent. The absorption in the prismatic, diffusing and opal glasses used in this country is not significantly greater than that in German glasses, and, indeed, in many cases the British glasses have a lower absorption factor. The improvement in

the Ruhr coal-fields reported by the author must have been due primarily to a more suitable combination of opal glass with the metal work of the lamp.

Mr. G. M. HARVEY said that whilst the author had spoken of the unfortunate history of the early attempts at coal face lighting up to now and the reasons for their failure, he had failed to stress one of the most important, viz., that so aptly described by Mr. Jones as the "nuisance value" of the installation. At the end of a working shift at the coal face, a row of props has sprung up perhaps 3 ft. or 4 ft. apart along the new line of the face, and before another shift started, the lamp fittings with the cable connecting them had to be moved from the back of this row of props and re-erected in the front. That, as much as, if not more than anything else, had contributed to the failure of the attempts at coal face lighting in the past, and until some arrangement had been devised which would make it easy and cheap to move and re-erect the lights in the new position, we should not gain much by considering standards of illumination.

Reference had been made in the paper to the sodium vapour lamp. This suffered from one very serious drawback which was that, if the tube was broken, small particles of metallic sodium were released, and if they dropped on moist ground they might cause a flame. However, he had seen one installation of sodium vapour lamps in a roadway in a South Wales colliery and was very much impressed by the way in which objects stood out against the background. It seemed to him that sodium possessed some quality which enabled the object to be illuminated to a degree which the background did not attain, so that the objects stood out in some way better than was the case with other types of illumination.

THE PRESIDENT recalled a meeting of the Society, held many years ago, when Dr. Llewellyn dealt with this subject adducing evidence that miner's nystagmus was primarily due to the exceedingly low illumination in use in mines at that time. The effect on the retina of such a feeble order of brightness was that it was impossible to see with the centre of the eye. Therefore, there was a tendency to continual effort to see "out of the tail of the eye" and to get the benefit of the greater sensitiveness of the periphery of the retina. It was suggested at that time that the use of a yellow bulb might be helpful because of the sensitiveness of the centre of the eye to yellow light, to which the peripheral part of the retina is relatively insensitive. The hope was that by adopting this device, the miner would be compelled to use the centre of the eye and the oscillating movement of the eyes would be checked. However, he imagined that was a condition which was found only with a very weak illumination indeed and the progress indicated in the paper might perhaps ultimately render nystagmus a disappearing disease.

As regards the colour of the fluorescent lamp and the use of light of other colours than daylight, there were instances in which a special colour was useful. He believed it was a fact that in separating dross from coal, the light from the mercury vapour lamp accentuated the difference in hue between coal and shale. There were opportunities for many different forms of lighting in various sections of mines, though doubtless portable lamps would continue to be used for many years to come.

THE AUTHOR, replying to the discussion, said that in German pits, when compressed air was available, a turbo-generator was frequently employed to supply the current for a number of lamps on the coal face. Personally, he felt

that if mains lighting for the coal face was not possible and compressed air was available, then the compressed air should be taken right to the coal face and individual generator lamps used there. He expressed appreciation of the remarks by Mr. Crawford and said he felt the National Coal Board would look with sympathy on the ideal suggested by Mr. Jones of having only four types of miners' lamp bulbs. With reference to Mr. Widnall's contribution, he wished figures with regard to glare were available. A great deal of work remained to be done both psychologically and by actual measurement relative to the subject of glare, and if a satisfactory means of measuring glare could be arrived at it would be of the greatest possible advantage because he believed it was one of the most important things to be considered in mine lighting, particularly at the coal face. From the glare point of view, he could hardly accept the view that lamps should be put across the roadways, and believed that to obtain the most efficient lighting free from glare the fluorescent tube lamps should be placed along the roadways.

As to the visual tasks of the miner, concerning which Mr. Minchin asked for further information, these were very varied. There was the getting of the coal and the shovelling of it after it had been brought down, and the placing it on the conveyer. Perhaps the placing of it on the conveyer was the most important because it was a task of some precision, and he felt that the fluorescent lamp would be helpful since it could be made to illuminate both the coal face and the conveyer. It might also be made to include the gob, as Dr. Withers had mentioned. All things considered, he thought that the fluorescent type of lighting was the best.

He thanked Mr. Sach for pointing out the error in the paper with regard to argon, and he had made the necessary correction. The same speaker and others had mentioned miners' nystagmus. The British Colliery Owners' Research Association had started to investigate that subject, and their studies were getting well on the way when the National Coal Board took over. The Board, however, intended to pursue the investigations, which would be carried out in very close liaison with their illumination researches.

The colour of lighting had been referred to, and he had a great deal of sympathy with what Mr. Holmes had said on that matter. In the paper he had suggested a compromise between daylight and a warm white, but it was surprising how quickly one could get used to the daylight colour. What appeared to be too blue at first soon ceased to be objectionable.

They would all agree with Mr. Richards that the hand lamp was a passing phase and that in future it would be used only in emergency or as an aid in getting to work. As to the graphs to which Mr. Richards drew attention, he said the fluorescent lamp was helping very much in the direction indicated.

Everybody would agree with Mr. Howell that everything possible should be done to eliminate glare, and he thought the suggestion to experiment with "off-white" instead of dead white for walls was a good one. Attempts had been made with a number of dusts applied to the roof and pack walls at the coal face with a cement gun, but so far a simple way of whitening the coal face had not been found. To be effective it would have to be done at least every second working shift. He hoped they would have success in this direction even if it were only the whitening in the neighbourhood of the lamp. For the success of any form of really improved lighting he felt that it was essential to increase the reflectivity of the background.

Finally, he said he was grateful to Mr. Penny for his contribution on the intrinsic safety of the fluorescent lamp. A cold-starting, hot-running lamp would

be very useful if it were intrinsically safe when broken and yet during normal running give the high output of lumens per watt.

Further Reply by the Author.

Mr. Crawford had referred to the lighting of pit cages. He, the author, felt very strongly that they should aim at a lighting system which would, as Mr. Crawford had said, give the men who worked underground a good light from the time they left the surface. He felt that the psychological effect of being plunged in darkness at 30 to 40 miles per hour from bright sunlight was a serious deterrent to recruitment. There was also the actual wastage of time in "getting their eyesight," which in total must amount to a great many man hours.

Mr. Richards had referred to the peaks shown in the graphs depicting the results obtained on the imitation coal face in the laboratories at the Royal School of Mines. In coal face lighting it was impossible to completely eliminate these peaks, but naturally it would be their endeavour to even out the illumination to the greatest extent possible. Fluorescent tube lighting combined with a white reflecting surface is the most practical way for doing this.

He agreed wholeheartedly with Mr. Howell about the "disability glare" from miners' cap lamps. The difficulty of lighting thin seams by mains lighting was real, but could, he felt, be overcome by the design of lamps, particularly in regard to the method of suspension. It was all-important to be able to fix the lamp as near to the roof as possible.

With reference to Mr. Howell's comment on the safety of the fluorescent lamp, while not intrinsically safe, it was certainly safer than the tungsten filament lamp.

Dr. Withers had rightly referred to the part that air-borne dust played in reducing illumination, not only by the absorption of light by the dust particles in the air, but also through the scatter of the light, particularly by stone dust particles, with resultant visual discomfort and reduction of light upon the object which it is desired to view.

He agreed with Mr. Harvey that the nuisance of disconnection, moving fittings forward, and re-connection as the face advanced, was one of the biggest factors working against the installation of mains lighting, and he regretted not stressing this more in his paper. Until the care and maintenance of lighting at the coal face (including whatever method was adopted for increasing the reflectivity in the vicinity of the lamps) was made the responsibility of one man, he doubted if mains lighting would ever succeed. Mr. Harvey's comments concerning sodium vapour lighting interested him particularly because he had always felt there was something about this type of lighting which enabled objects to be viewed with greater visual comfort than was the case with certain other types of illumination.

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